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Iida et al.

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(54) **VARIABLE INDUCTOR**

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(73) Assignee: **Murata Manufacturing Co., Ltd.**, Kyoto (JP)

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(52) **U.S. Cl.** **336/200**; 336/83; 257/531
(58) **Field of Search** 336/83, 200, 223, 336/232, 137; 257/531

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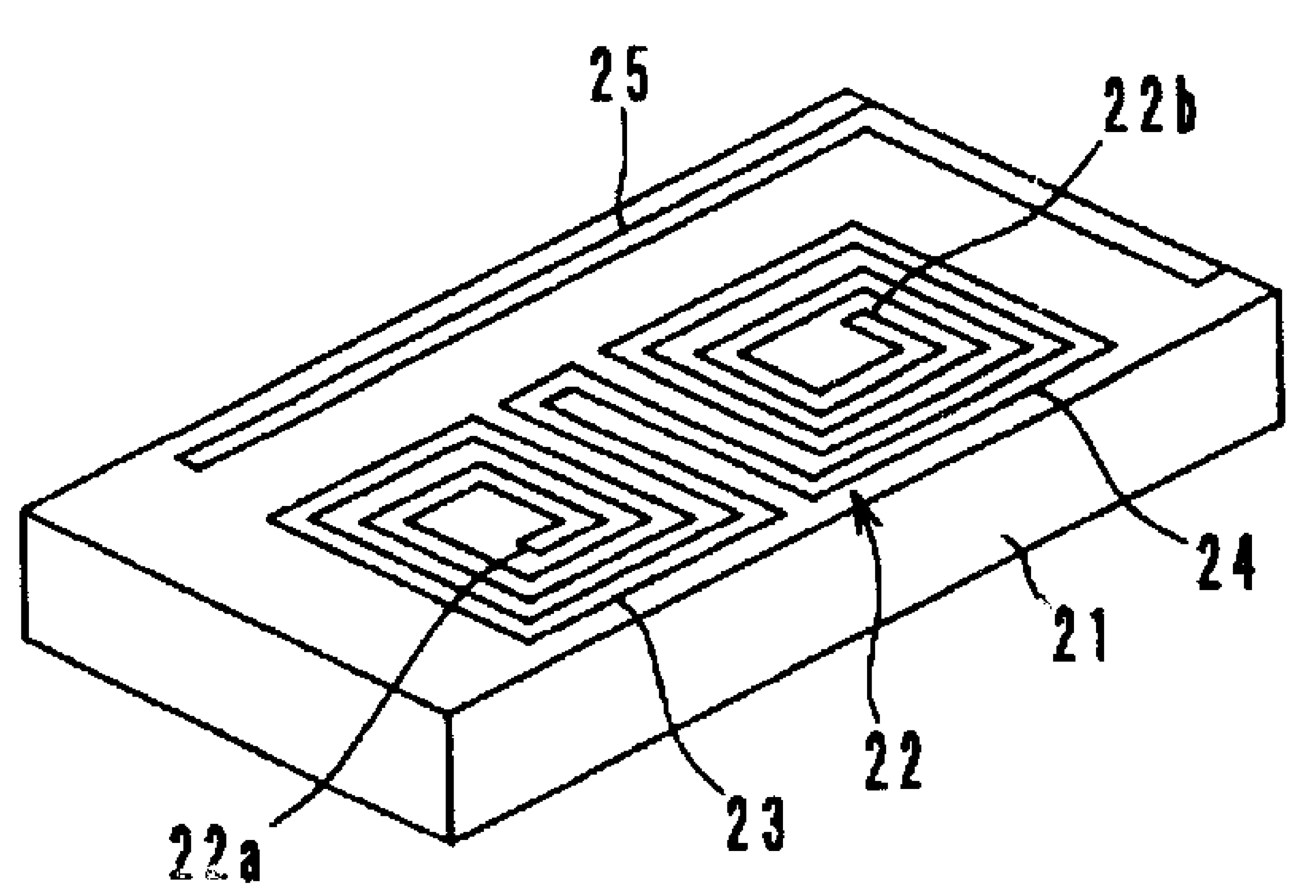
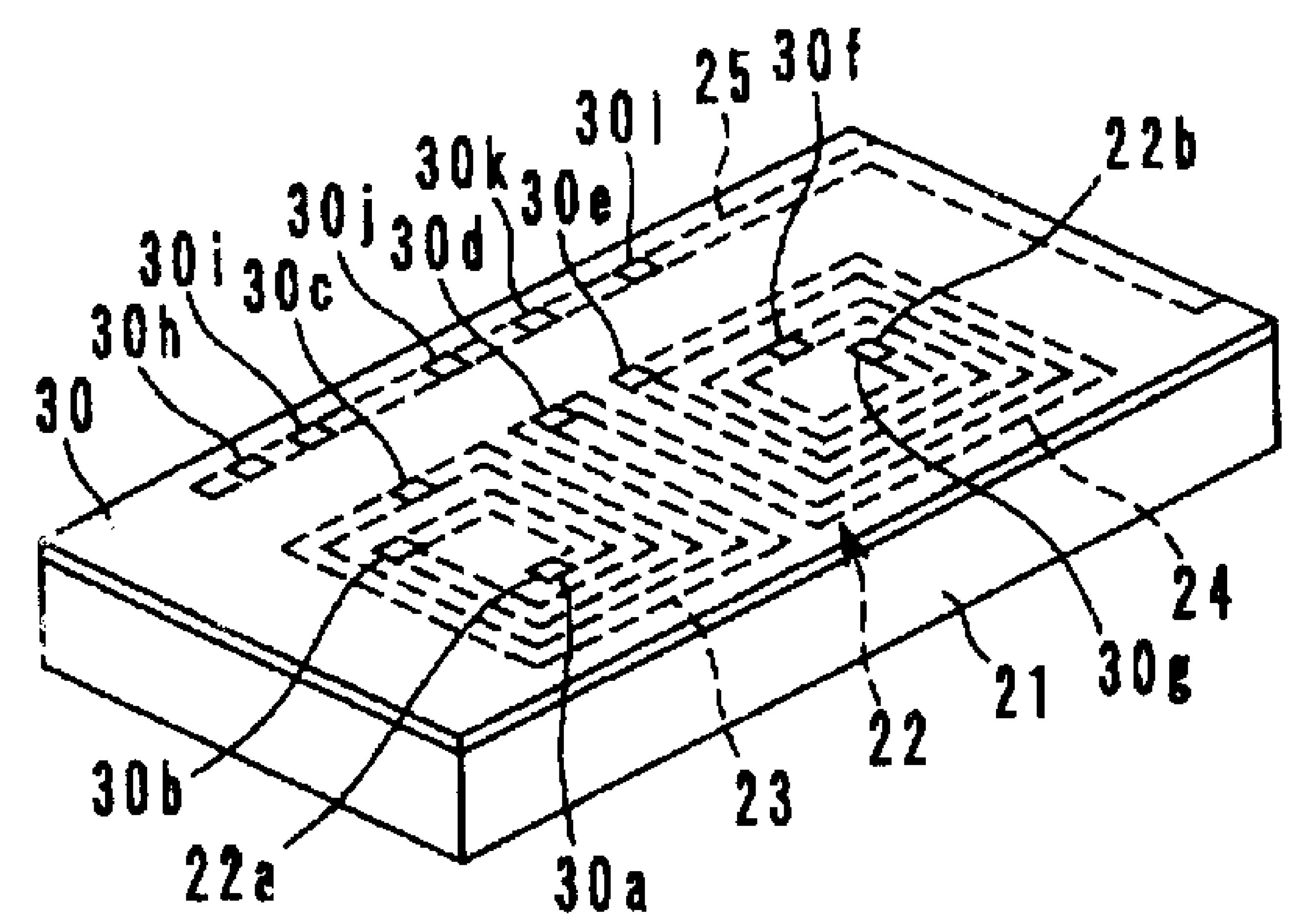
(57) **ABSTRACT**

A variable inductor includes an input external electrode, an output external electrode, and a coil formed by electrically connecting at least two spiral coil pattern portions in series between the input external electrode and the output external electrode. At least one trimming electrode is further provided in each of the spiral coil pattern portions. A first end and a second end of each trimming electrode are connected to the spiral coil pattern portion, and a lead out electrode, respectively, so that the trimming electrode bridges between the lead out electrode and the coil. The trimming electrodes are sequentially trimmed one-by-one, by, for example, irradiating a laser beam, starting from a trimming electrode closer to an edge, whereby the inductance of the coil is increased accordingly.

10 Claims, 5 Drawing Sheets





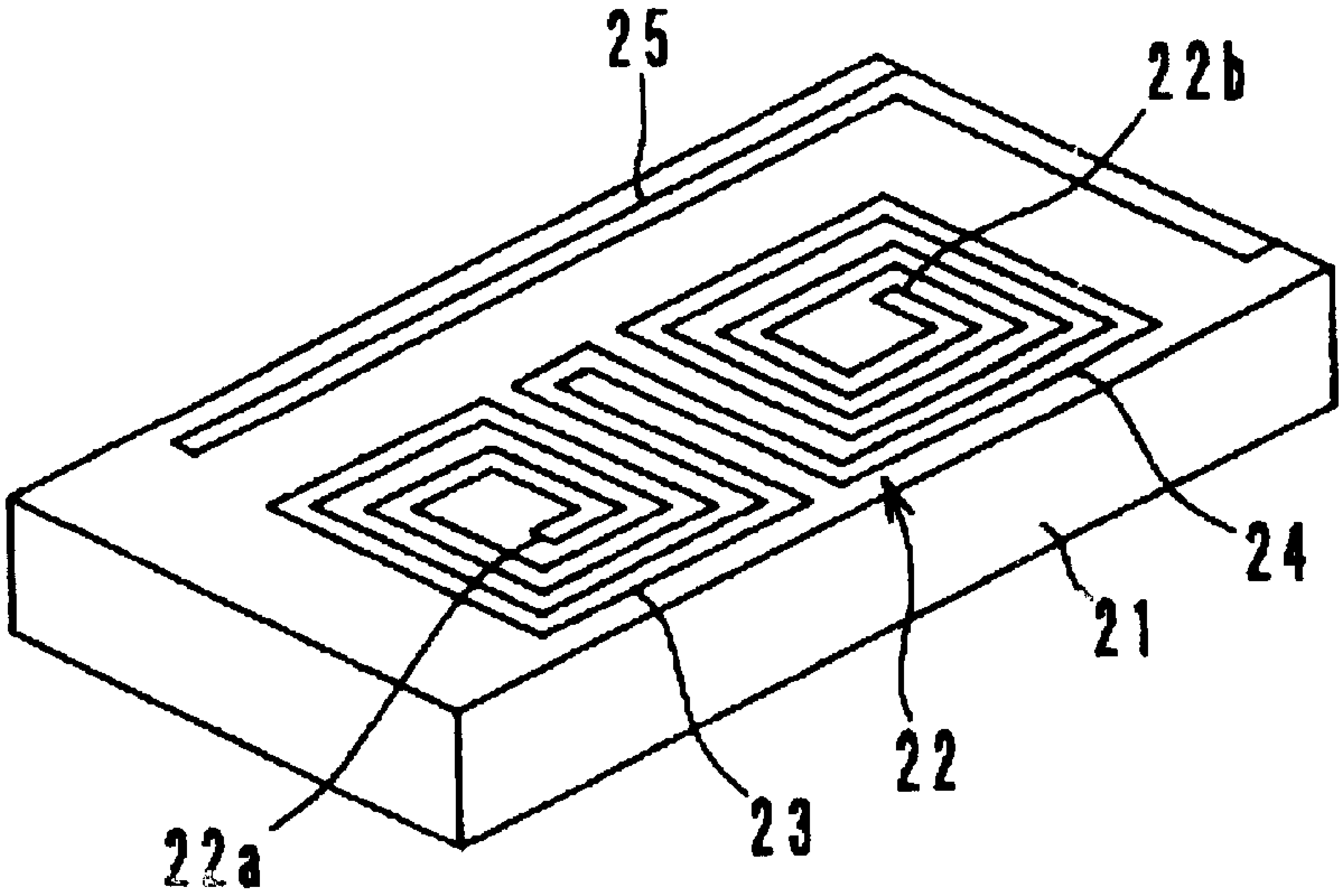

25
22b
24
21
22
23
22a

FIG.1

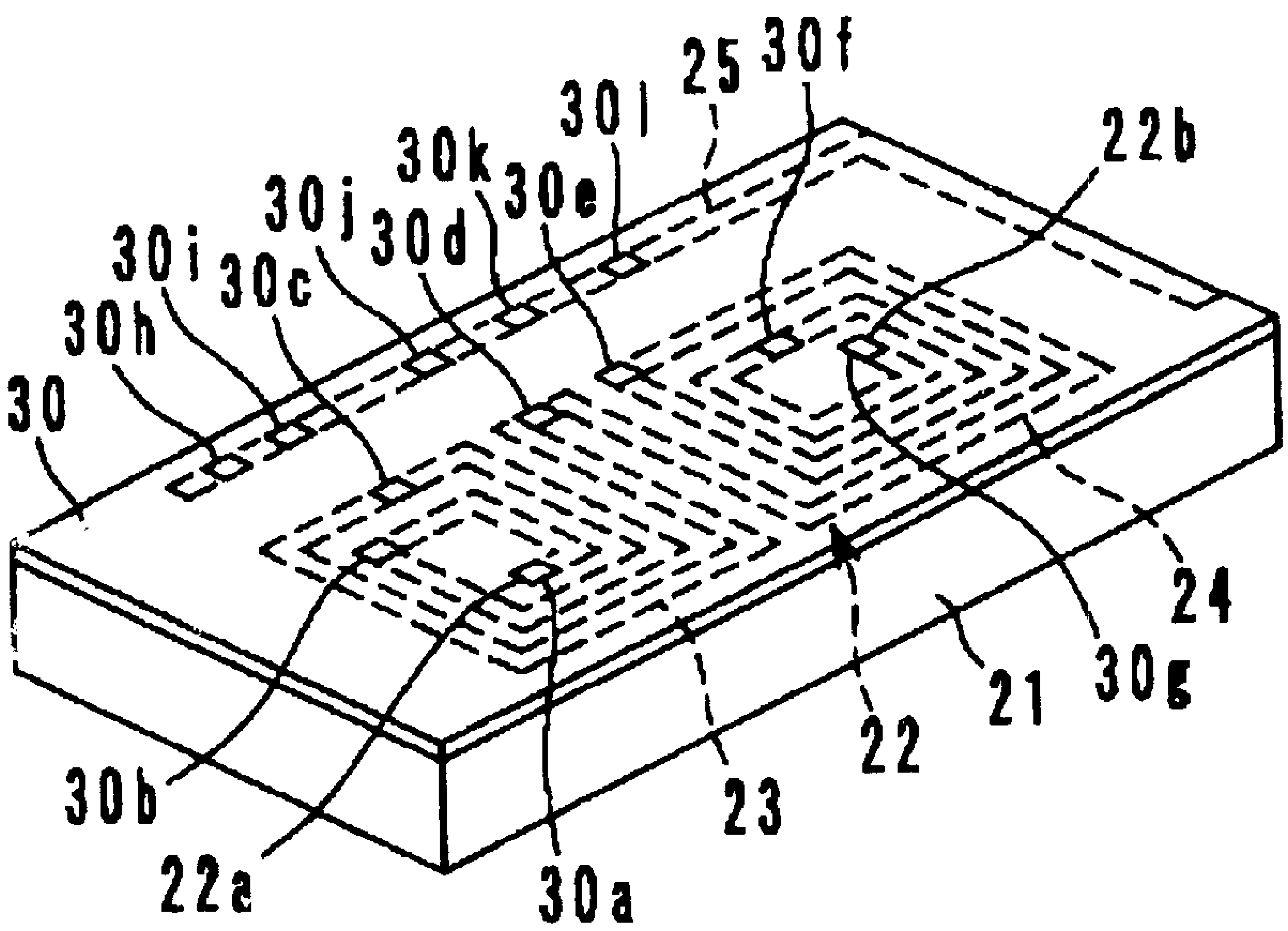

25
30f
30l
30k
30e
30j
30d
30i
30c
30h
30
22b
24
30g
21
22
23
30b
22a
30a

FIG.2

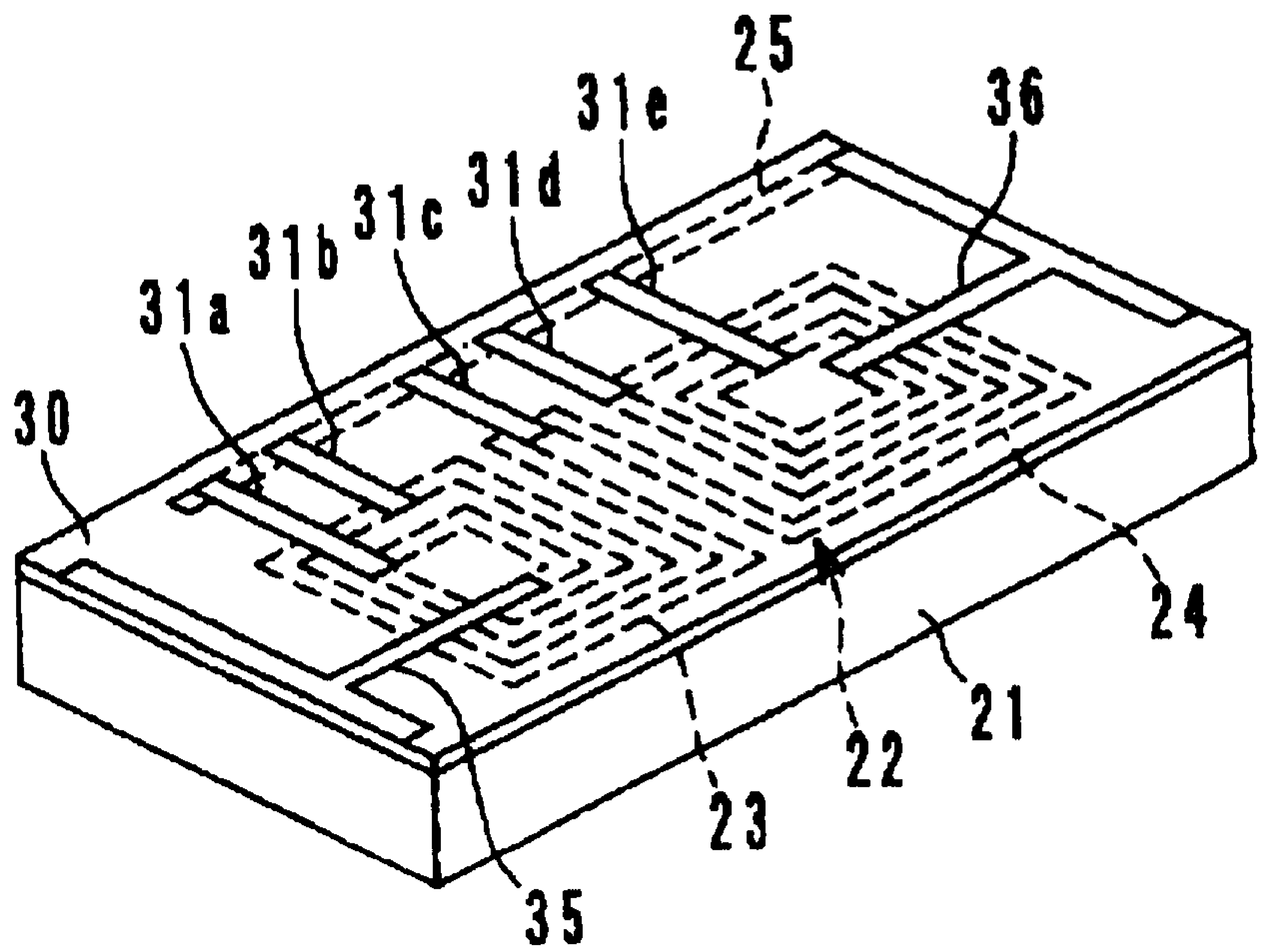

25
31e
36
31d
31c
31b
31a
30
24
21
22
23
35

FIG.3

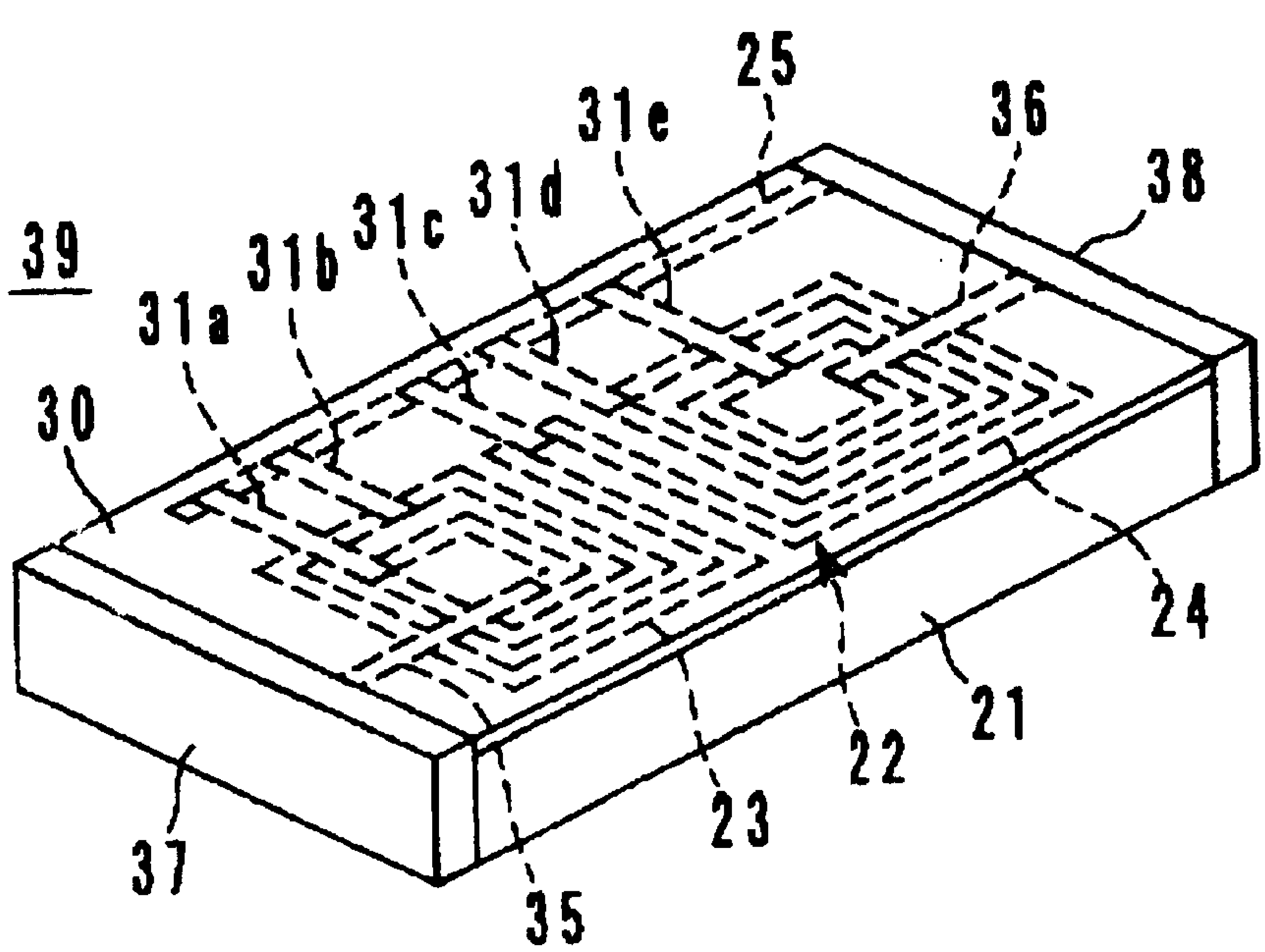

25
31e
36
38
31d
31c
39
31b
31a
30
24
21
22
23
37
35

FIG.4

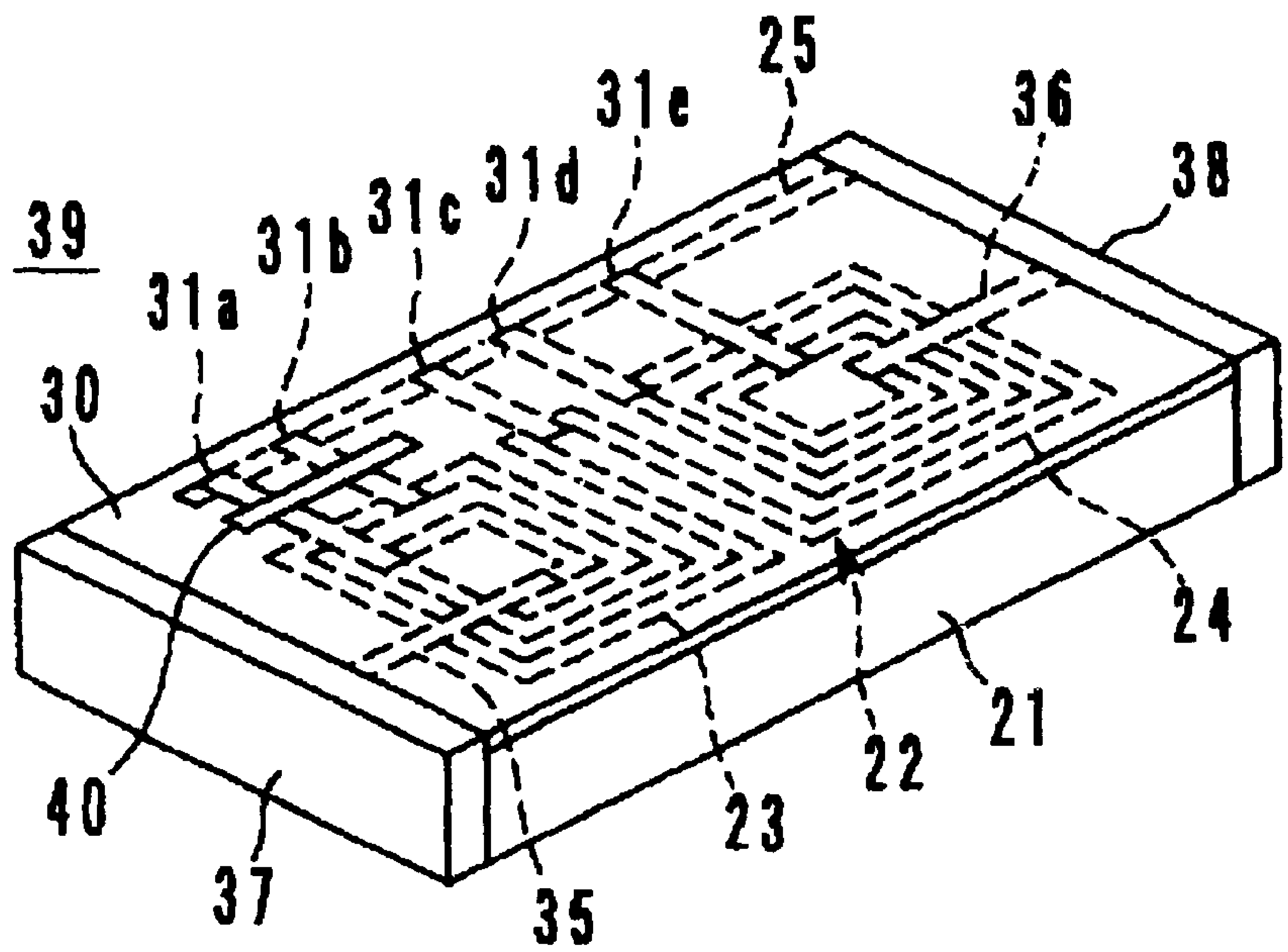

39
31a
31b
31c
31d
31e
25
36
38
30
24
21
22
23
40
37
35

FIG.5

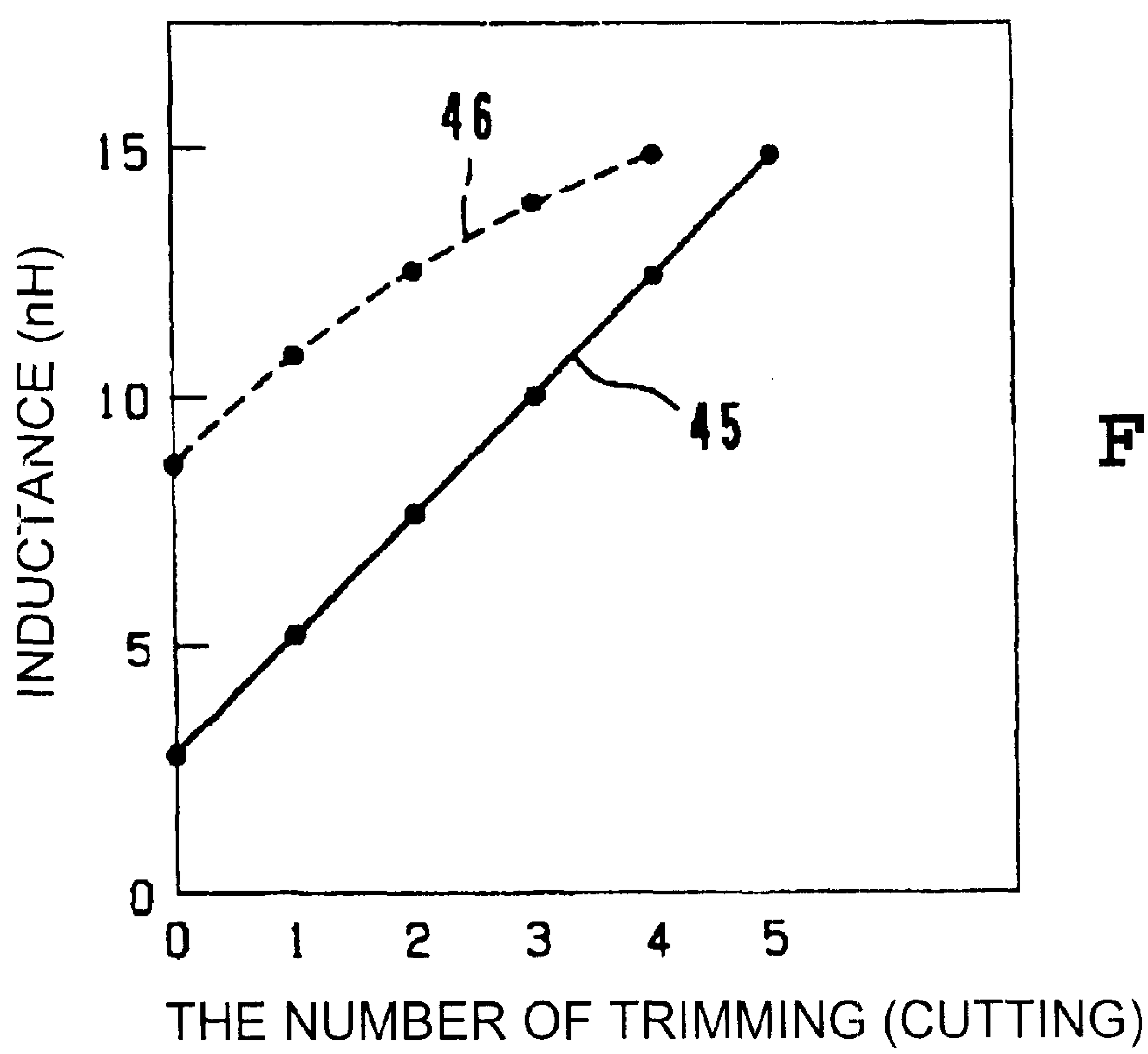

46
45
INDUCTANCE (nH)
0
5
10
15
0
1
2
3
4
5
THE NUMBER OF TRIMMING (CUTTING)

FIG.6

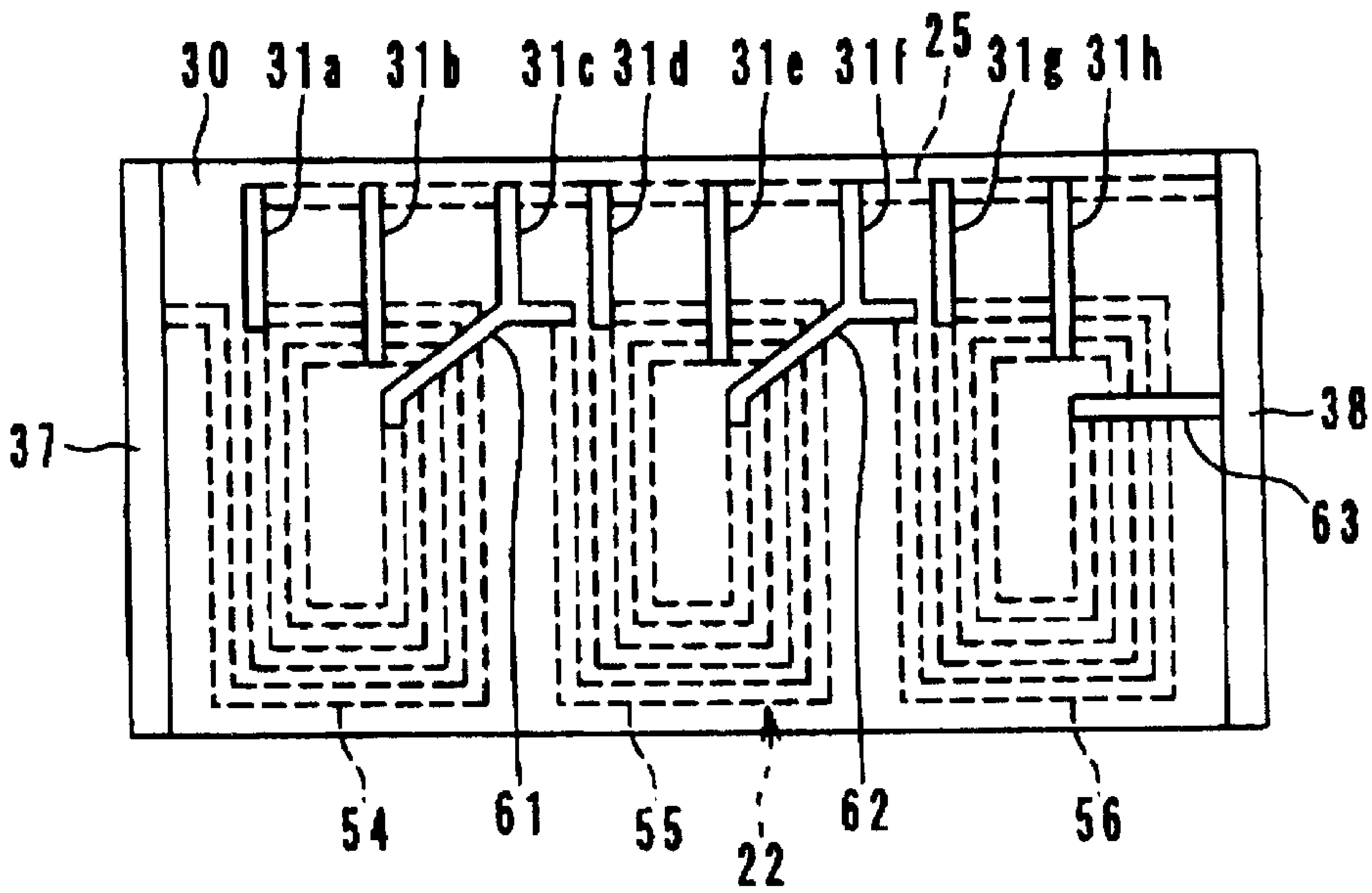


FIG.7

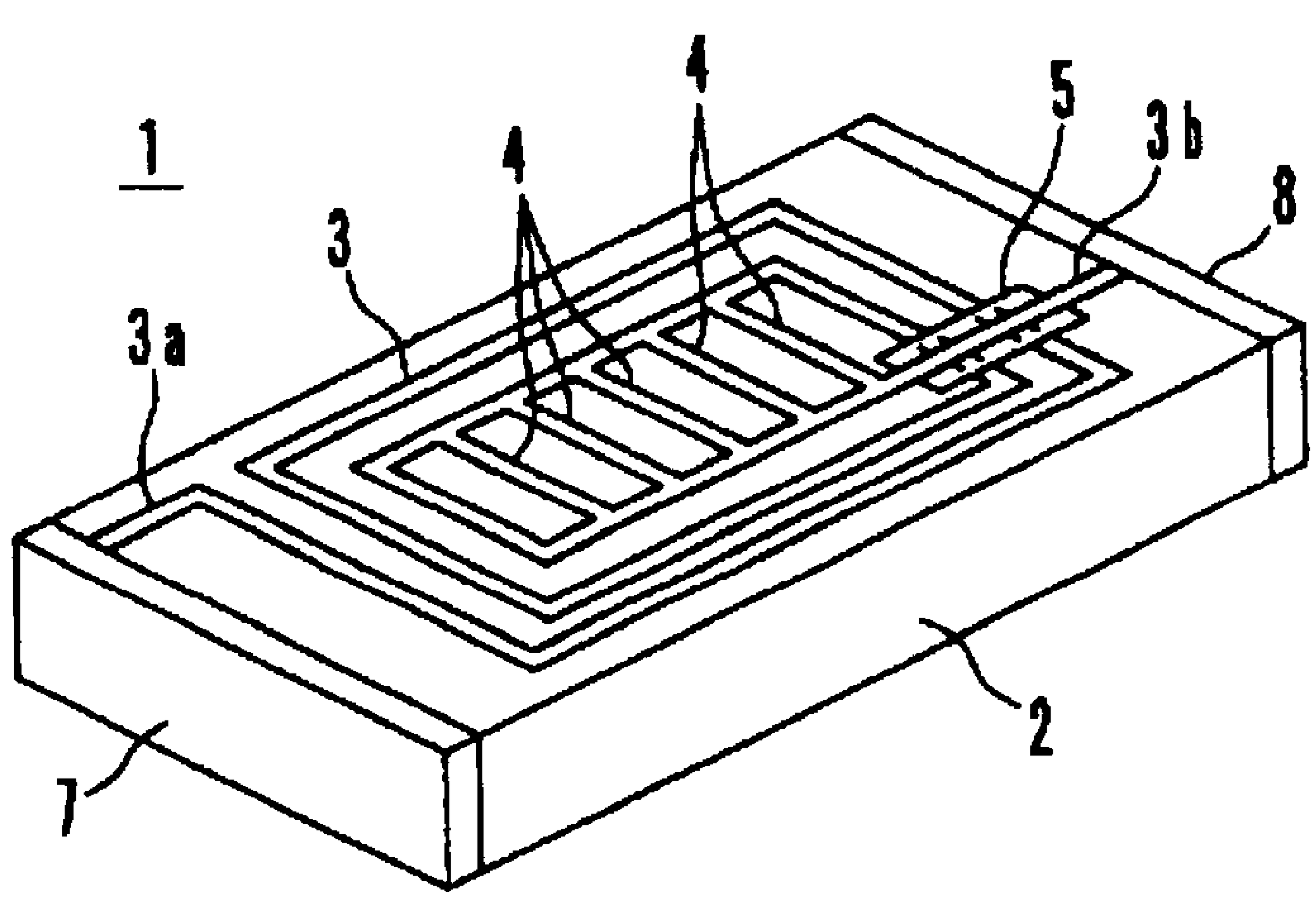


FIG.8
PRIOR ART

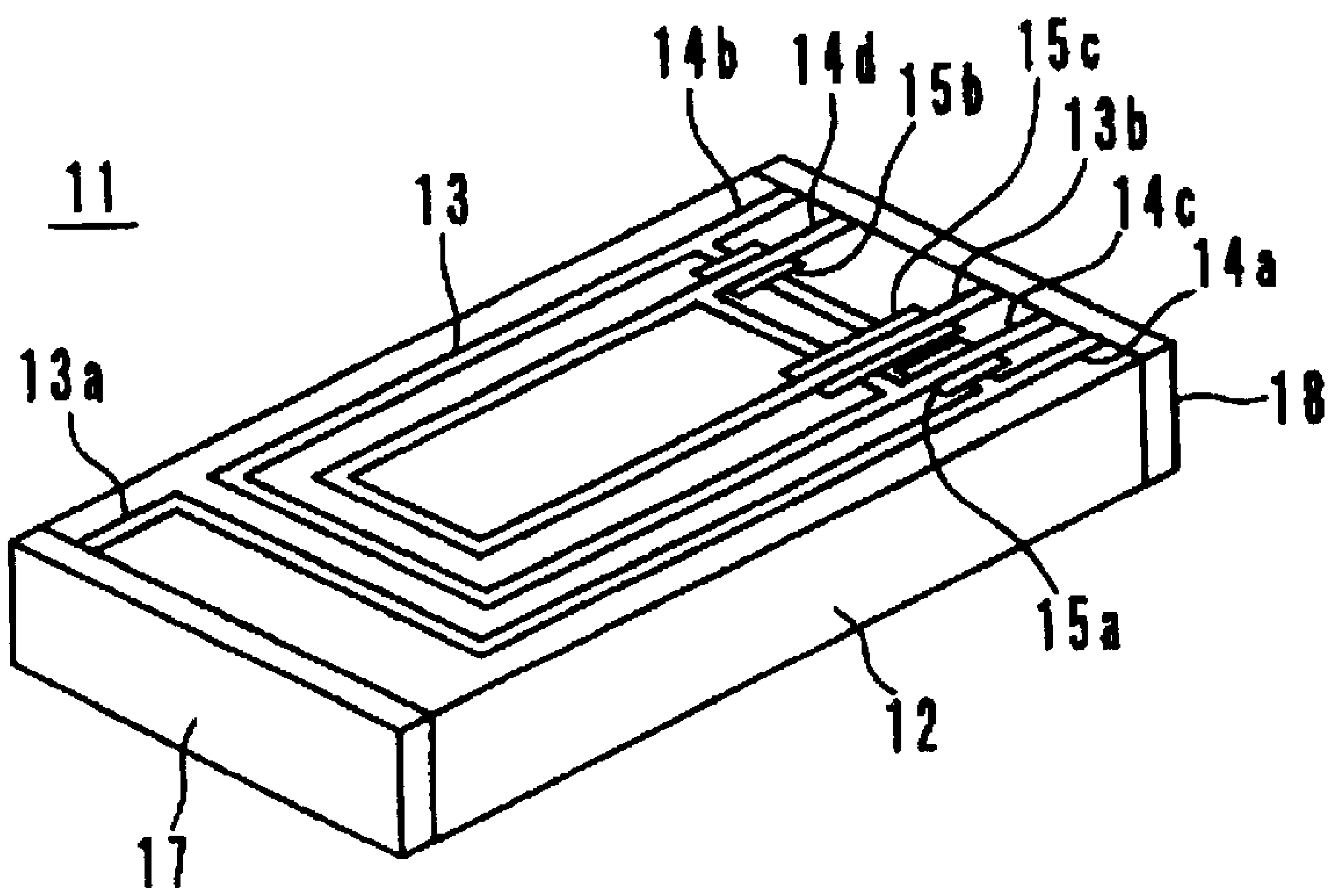


FIG.9
PRIOR ART

VARIABLE INDUCTOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to variable inductors, and more particularly, to a variable inductor for use in mobile communication devices.

2. Description of the Related Art

Electronic devices that are desired to be compact, in particular, mobile communication devices such as cellular telephones and automobile telephones, require compact components incorporated therein. Furthermore, as the frequency of operation of a device increases, the circuit becomes more complicated, and narrow variation and strict tolerance are required for the components incorporated therein. In effect, however, each component has the variation, and a circuit on which such components are merely mounted may not be correctly operated. In order to avoid such problems, methods have been conceived in which variable components are used for some of the components constituting the circuit, such that the variable components are finely adjusted to correctly operate the circuit. One method is to use variable inductors and one such conventional inductor has an inductance adjustment portion (trimming pattern portion).

FIG. **8** is a perspective view of an exemplary variable inductor **1** having an inductance adjustment portion. The variable inductor **1** includes a spiral coil **3** disposed on the surface of an insulating substrate **2**. The inductance adjustment portion includes a plurality of trimming electrodes **4** which are arranged in a ladder configuration, and is located in a region defined by the coil **3**. One end **3***a* of the coil **3** is electrically connected to an external electrode **7**, and the other end **3***b* extends across an insulator film **5** and is electrically connected to an external electrode **8**. The trimming electrodes **4** are sequentially trimmed one-by-one by irradiating a laser beam from above the variable inductor **1**, so that the inductance between the external electrode **7** and the external electrode **8** may be finely adjusted in a stepwise manner.

FIG. **9** is a perspective view of another conventional variable inductor **11**. The inductor **11** includes a spiral coil **13** disposed on the surface of an insulating substrate **12**. An inductance adjustment portion includes trimming electrodes **14***a* to **14***d*, and the trimming electrodes **14***a* to **14***d* are extended halfway from the coil **13** to the outside of a region defined by the coil **13**. The trimming electrodes **14***c* and **14***d* are located on insulator films **15***a* and **15***b* , respectively. One end **13***a* of the coil **13** is electrically connected to an external electrode **17**, and the other end **13***b* extends across an insulator film **15***c* and is electrically connected to an external electrode **18**. The trimming electrodes **14***a* to **14***d* are sequentially trimmed one-by-one so that the inductance between the external electrode **17** and the external electrode **18** may be adjusted.

However, the variable inductor **1** shown in FIG. **8** has a small area where the inductance adjustment portion is disposed, thus providing a small variable range for the inductance, making it difficult to acquire a variable inductance range required for a circuit adjustment. This is because increasing the area where the inductance adjustment portion is disposed in order to obtain a required variable range prevents compactness of the inductor. Furthermore, the variable inductor **1** is designed so that the electrodes **4** are arranged in a region defined by the coil **3**, and the electrodes **4** become obstacles to a magnetic field generated by the coil **3**. As a result, a problem occurs that the Q factor of the inductor **1** is reduced.

In the variable inductor **11** shown in FIG. **9**, on the other hand, the inductance is adjusted per turn, and the inductance is not finely adjusted. Hence, even if the variable inductor includes the optimum inductance for a circuit adjustment within the variable range thereof, there was a case where the optimum value could not be obtained. In addition, the variable inductor **11** makes it difficult to connect the trimming electrodes **14***a* to **14***d* at a substantially uniform interval of coil length, resulting in difficulty in accurately adjusting the inductance in a stepwise manner by a substantially constant value. Furthermore, since the trimming electrodes **14***a* to **14***d* are not arranged in a row in the trimming order, the trimming operation is cumbersome and is not suitable for mass production.

SUMMARY OF THE INVENTION

In order to overcome the problems described above, preferred embodiments of the present invention provide a variable inductor having a high Q factor and a wide variable range of inductance which can be finely adjusted with ease.

To this end, according to a preferred embodiment of the present invention, a variable inductor includes an input external electrode and an output external electrode, a coil defined by electrically connecting at least two spiral coil pattern portions in series between the input external electrode and the output external electrode, at least one trimming electrode provided in each of the at least two spiral coil pattern portions, each trimming electrode having one end connected to the spiral coil pattern portion, and a lead out electrode connected to the other end of each trimming electrode, wherein the lead out electrode is connected to one of the input external electrode and the output external electrode.

Preferably, the trimming electrodes are arranged in a row and are connected to the spiral coil pattern portions, such that the trimming electrodes are sequentially cut starting from a trimming electrode at an end, whereby the inductance of the coil is increased accordingly.

Accordingly, at least two spiral coil pattern portions are electrically connected in series between the input external electrode and the output external electrode to define a coil, where the trimming electrodes may be arranged in the trimming order. This facilitates the trimming operation, and avoids such an inconvenience as erroneous cutting during the trimming, thereby providing more reliable trimming. This further allows for a wider variable inductance range required for a circuit adjustment. The trimming electrodes are sequentially trimmed (cut) one-by-one so that the inductance of the coil may be finely adjusted in a stepwise manner by a constant value.

Other features, elements, characteristics and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Some illustrative preferred embodiments of a variable inductor according to the present invention will be described with reference to the accompanying drawings in conjunction with the following detailed description, in which:

FIG. **1** is a perspective view of a variable inductor according to a preferred embodiment of the present invention;

FIG. **2** is a perspective view of the variable inductor which is manufactured during a manufacturing procedure;

FIG. **3** is a perspective view of the variable conductor element which is fabricated during a manufacturing procedure;

FIG. **4** is a perspective view of an external appearance of the resultant variable inductor according to a preferred embodiment of the present invention;

FIG. **5** is a perspective view illustrating that some of the trimming electrodes are trimmed so that the inductance of the variable inductor shown in FIG. **4** may be adjusted;

FIG. **6** is a graph showing a variable inductance range of the variable inductor shown in FIG. **4**;

FIG. **7** is a plan view of a modification of the variable inductor according to the present invention;

FIG. **8** is a perspective view of a conventional variable inductor; and

FIG. **9** is a perspective view of another conventional inductor.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to FIG. **1**, a coil **22** and a lead out electrode **25** are provided on the upper surface of an insulating substrate **21**, which has been polished to be smooth, by thick-film printing or thin-film formation such as sputtering and deposition, or other suitable process.

Thick-film printing is a technique which includes providing a screen, for example, having openings in a desired pattern, over the upper surface of the insulating substrate **21**, and applying a conductive paste onto the screen to form relatively thick conductors (the coil **22** and the lead out electrode **25** in the present preferred embodiment) in a desired pattern on portions of the upper surface of the insulating substrate **21** which are exposed from the openings in the screen.

Thin-film formation may include a technique described below. A relatively thin conductive film is formed on substantially the overall upper surface of the insulating substrate **21**, and a resist film such as a photosensitive resin film is then formed on substantially the overall conductive film by spin-coating or printing. A mask film having a predetermined image pattern overlays the upper surface of the resist film, and a desired portion of the resist film is then cured such as by exposing it to ultraviolet rays. The resist film is peeled off with the cured portion being left, and the exposed portion of the conductive film is removed to form a conductor (the coil **22** and the lead out electrode **25** in the present preferred embodiment) in the desired pattern. Thereafter, the cured resist film is then removed.

Another possible formation process may involve a technique which includes applying a photosensitive conductive paste onto the upper surface of the insulating substrate **21**, and covering it with a mask film having a predetermined image pattern, followed by exposure and development.

The coil **22** is preferably formed by electrically connecting two spiral coil pattern portions **23** and **24** in series. The coil pattern portions **23** and **24** are arranged side-by-side in the longitudinal direction of the insulating substrate **21**. One end of the lead out electrode **25** is exposed on the right side of the insulating substrate **21**, as viewed in FIG. **1**. The materials of the insulating substrate **21** preferably include glass, glass ceramic, alumina, ferrite, Si, and SiO_2. The materials of the coil **22** and the lead out electrode **25** preferably include Ag, Ag—Pd, Cu, Ni, and Al.

Turning now to FIG. **2**, an insulating protection film **30** having openings **30***a* to **301** is preferably formed. Specifically, liquid insulating material is preferably coated on the entire upper surface of the insulating substrate **21** by spin-coating or printing, and is dried and fired to form the insulating protection film **30**. The insulating materials used herein include photosensitive polyimide resin, and photosensitive glass paste. Then, a mask film having a predetermined image pattern overlays the upper surface of the insulating protection film **30**, and the desired portion of the insulating protection film **30** is cured by, for example, exposing it to ultraviolet rays. The uncured portion of the insulating protection film **30** is then removed so that the openings **30***a* to **301** may appear. Exposed in the opening **30***a* is one end **22***a* of the coil **22** which is positioned inside of the spiral coil pattern portion **23**. The other end **22***b* of the coil **22** which is positioned inside of the spiral coil pattern portion **24** is exposed at the opening **30***g*. In turn, predetermined portions of the coil **22** are exposed in the openings **30***b* to **30***f*, and predetermined portions of the lead out electrode **25** are exposed in the openings **30***h* to **301**.

Turning now to FIG. **3**, trimming electrodes **31***a* to **31***e*, and lead out electrodes **35** and **36** are preferably formed by thick-film printing or thin-film formation such as sputtering and deposition, as is similar to the case of forming the coil **22**. The lead out electrode **35** is electrically connected to the end **22***a* of the coil **22** via the opening **30***a* in the insulating protection film **30**. The lead out electrode **36** is electrically connected to the end **22***b* of the coil **22** via the opening **30***g*. Likewise, first ends of the trimming electrodes **31***a* to **31***e* are electrically connected to the predetermined portions of the coil **22** via the openings **30***b* to **30***f* in the insulating protection film **30**, respectively. Second ends of the trimming electrodes **31***a* to **31***e* are electrically connected to the predetermined portions of the lead out electrode **25** via the openings **30***h* to **301**, respectively.

As viewed in FIG. **3**, the trimming electrodes **31***a* to **31***e* are arranged in a row in a ladder configuration at the rear of the insulating substrate **21**, i.e., are arranged at a side of the coil **22**, so as to bridge between the lead out electrode **25** and the coil **22**. The lead out electrode **35** is exposed on the left side of the insulating substrate **21**, while the lead out electrode **36** is exposed on the right side of the insulating substrate **21**.

As shown in FIG. **4**, liquid insulating material is coated on the overall upper surface of the insulating substrate **21** by spin-coating or printing, and the result is dried and fired, so that the insulating protection film **30** overlays the trimming electrodes **31***a* to **31***e* and the lead out electrodes **35** and **36**. Then, external electrodes **37** and **38** are formed on the ends of the insulating substrate **21** so as to extend in the longitudinal direction. The external electrode **37** is electrically connected to the lead out electrode **35**, and the external electrode **38** is electrically connected to the lead out electrodes **25** and **36**. The external electrodes **37** and **38** are formed preferably by applying conductive paste made of Ag, Ag—Pd, Cu, NiCr, NiCu, Ni, or other suitable material, and firing the result, followed by wet type electrolytic plating to form metal films made of Ni, Sn, Sn—Pb, or other suitable material. The external electrodes **37** and **38** may be otherwise formed by sputtering or deposition or other suitable process.

The resulting variable inductor **39** includes a circuit in which the coil **22** and the inductance adjustment portion (the trimming electrodes **31***a* to **31***e*) are electrically connected on the insulating substrate **21**. Since only a fraction of the trimming electrodes **31***a* to **31***e* is disposed in the region defined by the coil **22** on the substrate **21**, the magnetic field generated by the coil **22** is less blocked by the trimming electrodes **31***a* to **31***e*. Therefore, the inductor **39** has a very high Q.

After the variable inductor **39** is mounted on a printed board or other suitable substrate, the trimming electrodes **31***a* to **31***e* are trimmed, for example, irradiating a laser beam from above the variable inductor **39**, as shown in FIG. **5**, and thus, a trimming groove **40** is formed in the variable inductor **39**. The trimming electrodes **31***a* to **31***e* are sequentially cut one-by-one in the order starting from the trimming electrode **31***a* located at an end, and so on. It will be noted that FIG. **5** illustrates that the two trimming electrodes **31***a* and **31***b* are cut. Therefore, the inductance between the external electrodes **37** and **38** can be increased little by little in a stepwise manner by a constant value.

FIG. **6** is a graph showing the result of measurement on a change in inductance with respect to the variable inductor **39** having approximate dimensions of 2.0 mm×1.25 mm, as indicated by solid line **45**. For comparison, in FIG. **6**, the result of measurement on the conventional variable inductor **11** shown in FIG. **9** is indicated by dotted line **46**. The variable inductor **39** of the present preferred embodiment has a wide variable range from a low inductance of about 3 nH to a high inductance of about 15 nH. In contrast, the conventional variable inductor **11** has a narrower variable range of a relatively high inductance from about 9 nH to about 15 nH.

Since the variable inductor **39** is provided with the coil **22** including two spiral coil pattern portions **23** and **24** to which the trimming electrodes **31***a* and **31***b*, and **31***d* and **31***e* are connected, respectively, the trimming electrodes **31***a* to **31***e* may be arranged in the trimming order, thus facilitating the trimming operation. In addition, the trimming electrodes **31***a* to **31***e* may be connected at a substantially uniform interval of coil length, allowing the inductance to be finely adjusted stepwise, namely, linearly, by a substantially constant value.

In order to more finely adjust the inductance, the number of trimming electrodes **31***a* to **31***e* may be increased. The trimming electrodes **31***a* to **31***e* can be trimmed not only by a laser beam but by any other suitable process such as sandblasting. It is sufficient for each of the trimming electrodes **31***a* to **31***e* to be electrically cut, and the trimming groove **40** does not have to have a physically recessed configuration. In particular, when the insulating protection film **30** is made of glass or glass ceramic, molten glass due to irradiation of laser beams may enter into the trimmed portions to form protection films after trimming. This prevents the trimmed electrode portions from being exposed.

The variable inductor according to the present invention is not limited to the illustrated preferred embodiments, and a variety of modifications may be made without departing from the spirit and scope of the invention.

Any number of spiral coil pattern portions, but more than one, which constitute a coil may be adapted, and the coil **22** may be defined by, for example, three spiral coil pattern portions **54**, **55**, and **56** which are electrically connected in series, as shown in FIG. **7**. In FIG. **7**, there are shown eight trimming electrodes **31***a* to **31***h*, and relay pattern portions **61** and **62** through which the coil pattern portions **54** to **56** are connected in series. A lead out electrode **63** is used to connect the coil **22** to the external electrode **38**. Accordingly, an increased number of spiral coil pattern portions allow the inductance to be more finely adjusted.

It is not necessary to connect trimming electrodes **31***a* to **31***h* to all of the coil pattern portions **54** to **56**. The trimming electrodes **31***g* and **31***h* may be omitted so that no trimming electrode is connected to the coil pattern portion **56**.

The illustrated preferred embodiments have been described with respect to the case of individual production. For mass production, an effective approach involves fabricating a motherboard (wafer) having a plurality of variable inductors, and cutting the motherboard into pieces for each product dimension by techniques such as dicing, scribing and breaking, and using laser during the final stage.

The variable inductor may also be designed so that a printed board on which a circuit pattern has been formed has more than one spiral coil pattern directly disposed thereon.

While preferred embodiments have been described above, it is to be understood that modifications and changes will be apparent to those skilled in the art without departing from the spirit of the invention. The scope of the present invention is therefore to be determined solely by the appended claims.

What is claimed is:

1. A variable inductor comprising:

an input external electrode;

an output external electrode;

a coil defined by at least two spiral coil pattern portions electrically connected in series between said input external electrode and said output external electrode;

at least one trimming electrode provided in each of said at least two spiral pattern portions, each trimming electrode having a first end connected to a respective one of said at least two spiral coil pattern portions; and

a lead out electrode connected to a second end of each of said trimming electrodes;

wherein said lead out electrode is connected to one of said input external electrode and said output external electrode.

2. A variable inductor according to claim **1**, wherein the trimming electrodes are arranged in a row.

3. A variable inductor according to claim **2**, wherein the trimming electrodes are connected to the spiral coil pattern portions, such that the trimming electrodes are arranged to be cut sequentially starting from a trimming electrode at an end so as to increase the inductance of said coil.

4. A variable inductor according to claim **1**, wherein the at least two spiral coil pattern portions are arranged side-by-side.

5. A variable inductor according to claim **1**, wherein the trimming electrodes are arranged in a row in a ladder configuration.

6. A variable inductor according to claim **1**, wherein the trimming electrodes are arranged at a side of the coil so as to bridge between a lead out electrode and the coil.

7. A variable inductor according to claim **1**, wherein the trimming electrodes define an inductance adjustment portion.

8. A variable inductor according to claim **7**, wherein the coil and the inductance adjustment portion are electrically connected.

9. A variable inductor according to claim **1**, wherein only a fraction of the trimming electrodes are disposed in the region defined by the coil.

10. A variable inductor according to claim **1**, wherein the coil is defined by at least three coil pattern portions which are electrically connected in series.

* * * * *